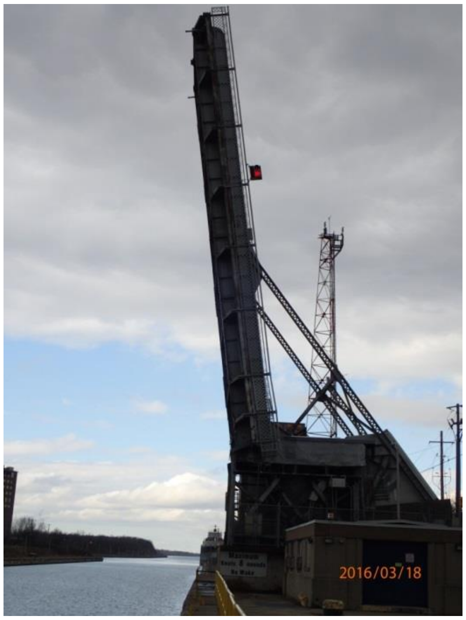

HEAVY MOVABLE STRUCTURES, INC.
16th BIENNIAL SYMPOSIUM

September 19-22, 2016

Main Street Bridge
Vessel Impact, Analysis and Repairs

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TAMPA MARRIOTT WATERSIDE HOTEL AND MARINA
TAMPA, FLORIDA

Introduction

The St. Lawrence Seaway is a commercial waterway that travels from the St. Lawrence River in Montreal to Lake Erie (Port Colborne). The Welland Canal portion of the St. Lawrence Seaway is from St. Catharines, Ontario (south end of Lake Ontario), to Port Colborne, Ontario (north end of Lake Erie). The canal is 43 km (27 miles) long and has an elevation change of 100 m (330 ft.) across the entire length.

The Main Street Bridge is a Scherzer style rolling lift bascule bridge at the north end of Lock No. 8 in Port Colborne, Ontario, Canada. Port Colborne is a community of approximately 20,000 people, located along the north shore of Lake Erie at the upper end of the Welland Canal.

Bridge 19 was designed in 1926-27 and has been operational since 1932. The bridge currently cycles approximately 3,000 operations per year. For several decades it was cycling at 5,000 operations per year. The bridge carries Main Street (two lanes) over the Welland Canal. There is a pedestrian sidewalk along both sides of the roadway, over the lift span. The structure has a span of 27.4m (90') and a width of 7.2m (23'6"). The travelled portion of the roadway is 6.1m (20') wide.

The bascule lift span superstructure consists of structural steel through plate girders with two cantilevered sidewalks. The two-lane grid deck is supported by floor beams (numbered 0 to 7 from East to West), and stringers between the plate girders. The roadway on the approach is asphalt paved. The roadway and sidewalks over the structure is open steel grating.

Location Plan of the Great Lakes Seaway

On September 30, 2015, a foreign vessel, the LenaJ, came into the lock, skewed and impacted the North girder of Bridge 19 while it was in the raised position.

Vessel Impact on North Girder Facing West

Vessel Impact on North Girder Facing North East

After an initial inspection of the critical elements, including drive machinery, rack and pinion, segmental girder and bridge structure, it was decided to operate the bridge in slow speed. The mechanical operation of the bridge appeared normal and no unusual noises were detected. The operation showed the bridge would not seat and the centering was interfering due to bridge misalignment. Two more bridge operations were done to observe if the bridge would find its center. However, the result was the same.

Bridge Deck misalignment After Impact

Short Term Actions

A local Structural Engineering Consultant was engaged to give an initial evaluation. Their findings concluded that the bridge loading should be reduced to 5 tons until a full evaluation was completed. Since The St. Lawrence Seaway Management Corporation (Seaway) has no control over the traffic crossing the bridge, it was decided to close the bridge to vehicular traffic but have it remain open for pedestrians and emergency vehicles travelling at reduced speed.

In order to have the bridge operational, the centering device was removed. It was also determined the limit switches for the bridge locks needed to be relocated so that the bridge would seat.

Centering Pin Removal

Limit Switch Flag Relocation

Further Investigation

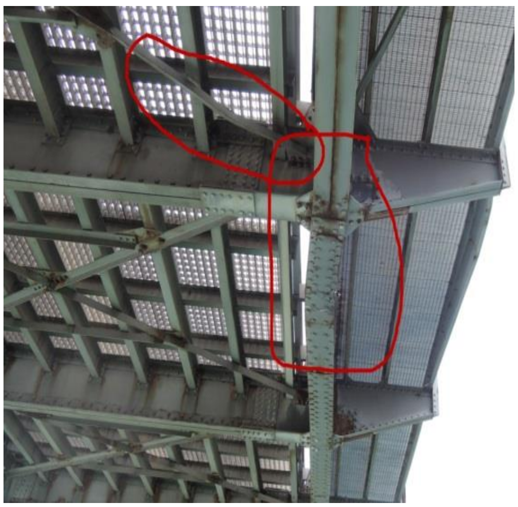
A detailed inspection was completed by the Seaway inspection group to gain a better understanding of the damage.

This inspection revealed the bridge was out of alignment at the toe end (West side), by approximately three inches (3”) towards the South and at the heel end (East side), by about ¾” (1.9 cm) towards the North. Floor beams FB1, FB2, FB3 and FB4 were slightly bent due to the collision and Bay 2, 3, 4 and 5 were also slightly deformed. The steel deck grating was in good condition with some slight overall deformation.

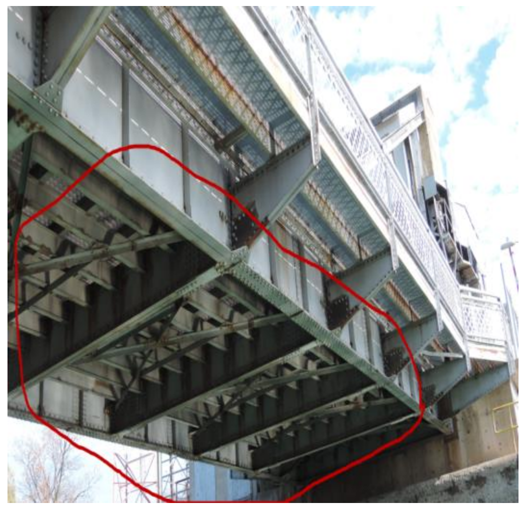
Both the South and North diagonal ties to the longitudinal through the plate girder had deformation at the lateral connection. The connection plates at the bottom of both North and South diagonals were also deformed. The rack support frames had local as well as slight global deformations. The bridge was rubbing against the rack support frame during the operation. The teeth at the track level were also rubbing against the tooth pit in the segmental girder. The track support girders and segmental girders were generally in good to fair condition. The segmental girder had some damaged stiffeners. The tracks and treads were in fair to good condition. The counterweight was in good condition. The machine room was in fair to good condition.

North Girder Impact Damage – Bottom of Girder

North Girder Impact Damage – Facing South



Cross Bracing Impact Damage



Global Deformation of Bay 1, 2 and 3

Deformation of South Girder Connection Plate

Gap Between Fixed and Movable Portion Reduced

North Girder Rubbing on Rack Support

The inspection recommended a load evaluation of the structure taking into account all of the defects and completing a fatigue analysis which would require a full model to be created. There were concerns that certain elements of the 85-year-old bridge would no longer have any remaining fatigue life.

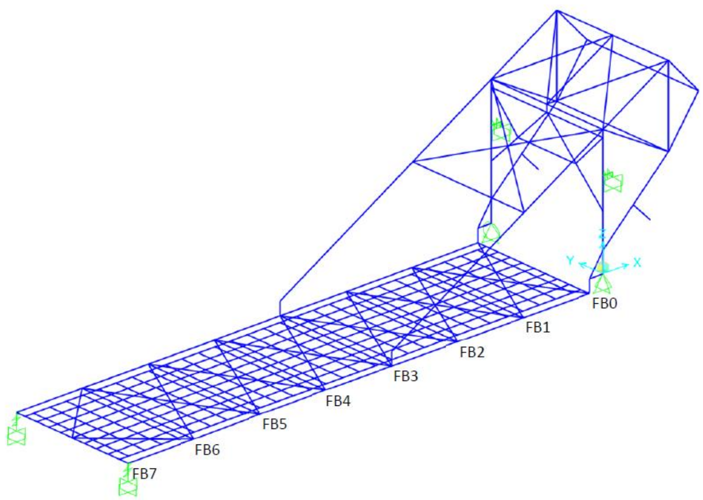
Course of Action

Hardesty & Hanover, LLP were retained to complete a site investigation to ascertain the current condition of the bridge due to the impact, and also to determine the current safe load capacity of the structure. In addition, they were to make recommendations regarding the operating conditions from the results of the investigation and load rating. The scope also included the development of analytical models to assess the structure, as well as development of repair and strengthening plans for members affected by the impact.

Hardesty & Hanover were awarded the work December 2, 2015, and were to have construction drawings completed by January 15, 2016. The construction contract was to be tendered, and awarded by February 1, 2016. All field work was to be completed by March 18, 2016. The St. Lawrence Seaway is shut down for the winter for approximately 10 weeks from January 1st to March 25th every year. This work had to be completed during this shutdown so as not to affect shipping traffic. There was also a commitment to the local community to have the bridge back in service as soon as possible as the bridge is part of a major roadway that joins other communities.

Analysis – Bridge Modeling

The purpose of this analysis is to evaluate the structural adequacy of the bridge under various loading conditions including dead, live, wind, and seismic loads. The analysis included the following: a live load rating of main floor system members for standard trucks as determined by CAN/CSA-S6-06 Bridge Code, and a wind and seismic evaluation of all members. Results of the analysis were used to determine bridge deficiencies, and provide recommendations for retrofit or repair.



3D Model of Bridge

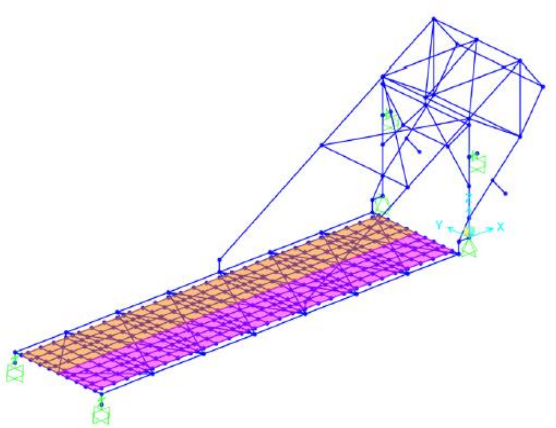
Findings and Recommendations

Live Load Rating

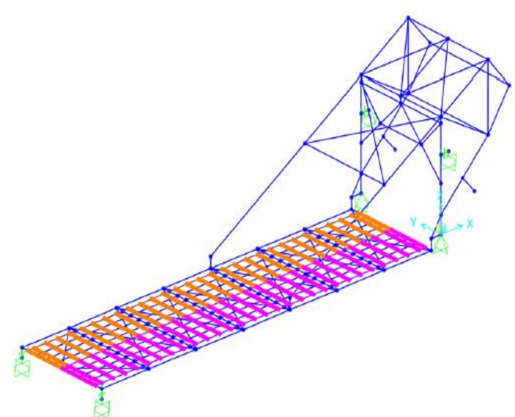
The findings indicated that the bridge has no deficiencies with respect to the as-built conditions. A live load rating for all main load carrying members was also determined. The live load rating is the measure of a member's remaining capacity to carry live load. A rating factor of 1.0 or greater indicates that the member can support the code prescribed live load for the bridge.

For Bridge 19, it was determined that all main members including bascule girders, floor beams, stringers and crossbeams have a live load rating factor, F, greater than 1.0, and are therefore sufficient for use by normal highway traffic.

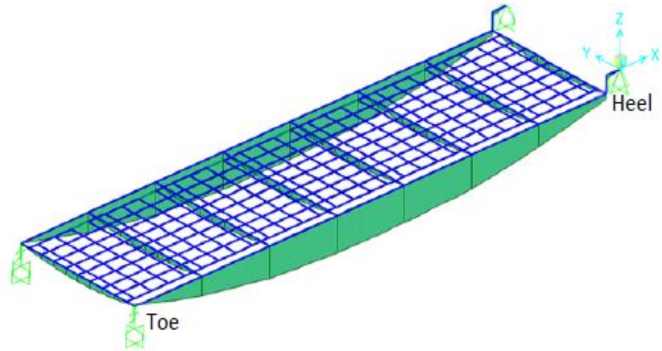
It was recommended that continued routine inspections of the bridge be performed and section loss and deterioration recorded, to be used for future load rating updates.



Live Load Lanes



Live Load Connections to Crossbeams



Bascule Girder Live Load Moment Diagram

Fatigue Evaluation

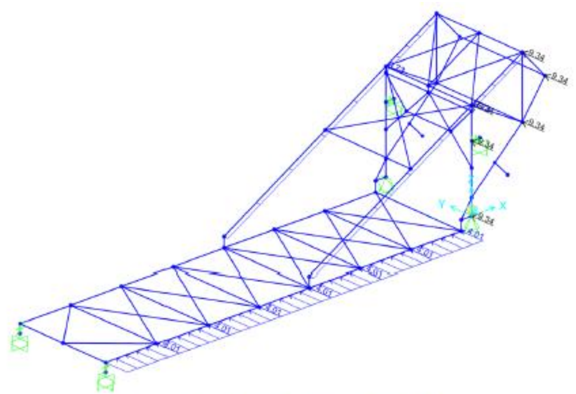
A fatigue evaluation of the bridge was performed to determine the effects of repeated live load on the bridge. This analysis is separate from the live load rating analysis, in that it does not evaluate member capacity, but instead the member's ability to be stressed and unstressed with the passage of vehicular traffic.

Several locations on the stringers and bascule girders were found to have limited fatigue life. This result is based on two assumptions that have a significant impact on the analysis. They are design life, and average daily truck traffic (ADTT). The code prescribed values were used to screen for fatigue, the code values are 75 years design life and ADTT of 1000, which considering the use of this bridge appear to be reasonable assumptions. The reason for this deficiency is that these members are comprised of riveted connections which do not have a theoretical long fatigue life. The actual number of fatigue cycles and stress range may be much lower than those estimated by the code prescribed methodology. A complete assessment of fatigue would require an accurate historical record of ADTT as well as the weight of trucks crossing the bridge. Neither of these is known with any certainty.

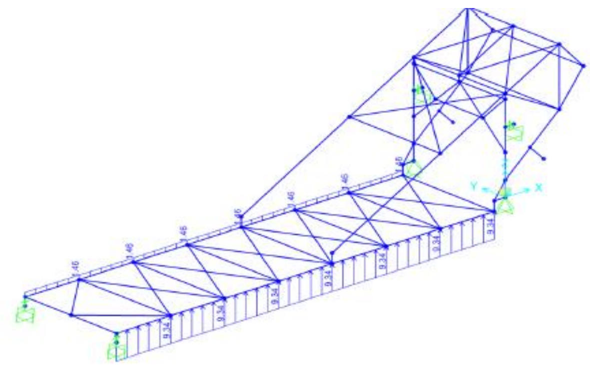
The inspection reports did not indicate that the bridge has experienced any fatigue cracks on the bascule girders or stringers. It was recommended that in addition to the required inspection every two years, an enhanced inspection be completed on a routine annual basis. This inspection would pay special attention to the riveted top flange of the bascule girder and connections of the stringers at the lateral bracing.

Wind and Seismic Evaluation

Wind and seismic forces were applied to the structural model in accordance with the design code. Separate models were prepared to account for bridge open and closed conditions. No deficiencies were identified with respect to the wind and seismic analysis.



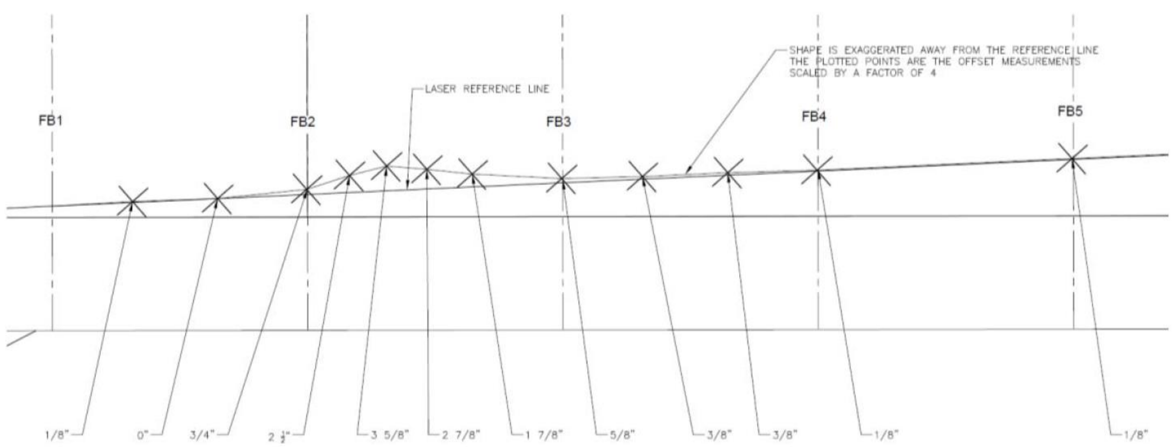
Wind Load –Horizontal (kN/m)



Wind Load –Vertical Eccentric(kN/m)

Ship Impact Evaluation

The ship impact was virtually re-created using several analytical software packages. This was done in order to understand the likely load path of the impact force, and determine if any members may have been damaged beyond those observed during the field inspection. The refined models show the girder that received the primary ship impact force. This location is between floor beam 2 and floor beam 3. At the worst point, 92 mm (3.625") deformation was measured.



Bascule Girder Measured Deformations

The localized concentration of the deformation was simulated as a single concentrated force. The results of the analysis indicates that the ship impact forces would have been on the order of 5,000kN (1,000 kips) or greater.

When this impact force was applied to the global model it revealed that many of the bridge members, including bracing, floor beams and stringers would have also been damaged as a result of the impact. However, these findings do not correlate with the damage that was observed by the in-depth field inspection. These conflicting findings indicate that there was more force distribution and dampening in the structure than what the 3D analytical model displayed.

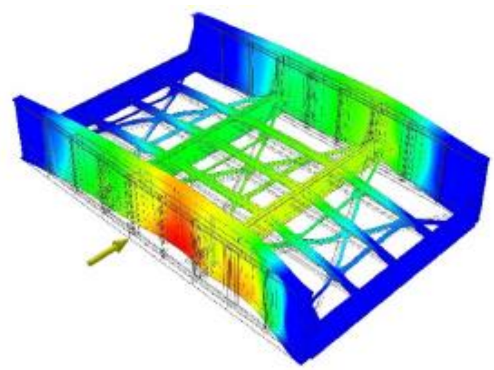
A large portion of the energy from the impact was likely dampened during the deformation of the girder and therefore not distributed throughout the structure as is predicted by the model.

An alternate approach in determining the global effect on the bridge was used. An iterative approach was used where the impact force was incrementally increased until the analytical results from the model matched the inspection findings.

Based on the damage that was observed during the inspection, the theoretical force that just slightly overstressed the bracing in Bay 1 and 2 was 800kN (175 kips) which represents a reasonable upper-bound estimate for the actual ship impact force.

This force distribution and the anticipated effects on the respective members correlate with the findings observed in the field.

3D Girder Model



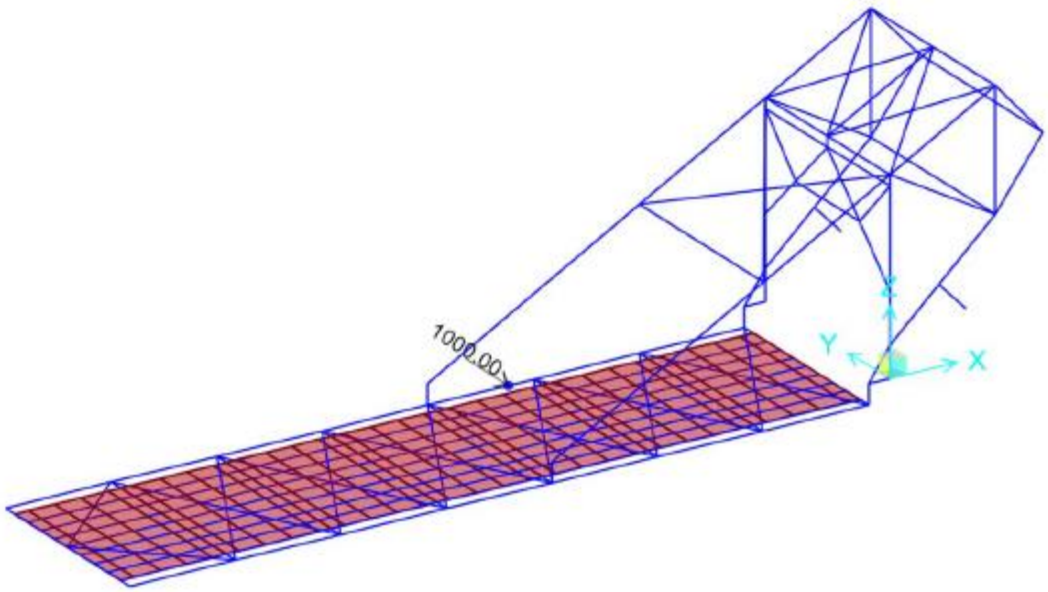
Typical Stress Plot due to Applied Force

The model used for the live load and wind and seismic analysis was further advanced and refined to determine the effects of the ship impact that occurred to the North bascule girder. The local effects of the ship impact were virtually recreated using Autodesk Simulation Mechanical 2016, which provides the ability to create a “Mechanical Event Simulation”, which can reproduce collision effects and its resulting deformations. The results of this analysis were used in the CSi Bridge global model to verify the load path of the ship impact force, and determine which members may have been overstressed.

The load path and likely damaged members were correlated to what was found during the in-depth field inspection of the bridge. The evaluation determined that beyond the local damage to the bascule girder and the bottom lateral bracing, no other members were significantly affected.

Any other minor yielding of floor beams or stringers will not affect the load carrying capacity of the members, the load rating of the bridge or have any negative long term residual effects. The bascule girder was also laterally deflected during the ship impact which caused a permanent lateral deformation. Accommodating this deformation will require modifications to the lock bars and centering guide at the toe of the span.

Straightening the bascule girders is not required for strength purposes and if left in its current condition will not have any negative long term residual effects. It was recommended that the local damage to the bascule girders be repaired, as well as replacement of bottom lateral bracing between the heel floor beam FB0 and floor beam FB3. I



Ship Impact Force Applied to Global Model

Recommended Repair Construction Cost Estimate

Bascule Girder Repairs (Including Jacking and Balance)	$ 450,000
Bracing, Lock Bar and Centering Guide Repairs	$ 150,000
Bascule Girder Straightening	$ 200,000
	Total $ 800,000

Included in the construction estimate is the cost for straightening the bascule girders. For this work to be performed, the bridge deck and crossbeams will need to be removed, and the girders jacked to retain its original configuration. Due to time constraints and the uncertainty of the overall success rate of straightening the bridge, straightening was not attempted at this time.

Site Work

Scaffolding under the bridge deck was first installed to gain access to all the damaged areas. The majority of the repair work involved removing a section of the North main girder. In order to maintain the North girder as a tension member, the bridge overhead counterweight was jacked to have it act as a simply supported structure, and top and bottom of the girder was jacked in compression and tension respectively.

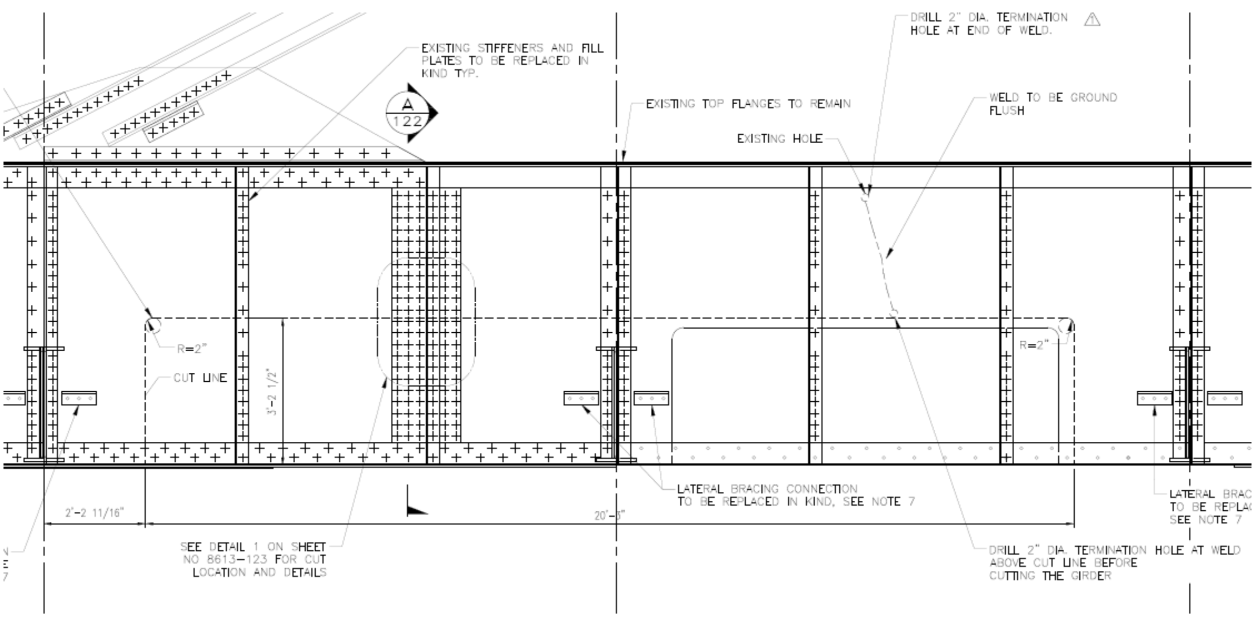
Scaffolding Installed

Overhead counterweight being jacked to relieve the forces applied by the counterweight stay connections. Static jack stands used in conjunction with smaller hydraulic jacks applying a total of 200 tons of pressure. Two pancake jacks were placed on the toe of the bridge to measure the downward force of 25 kips per girder.

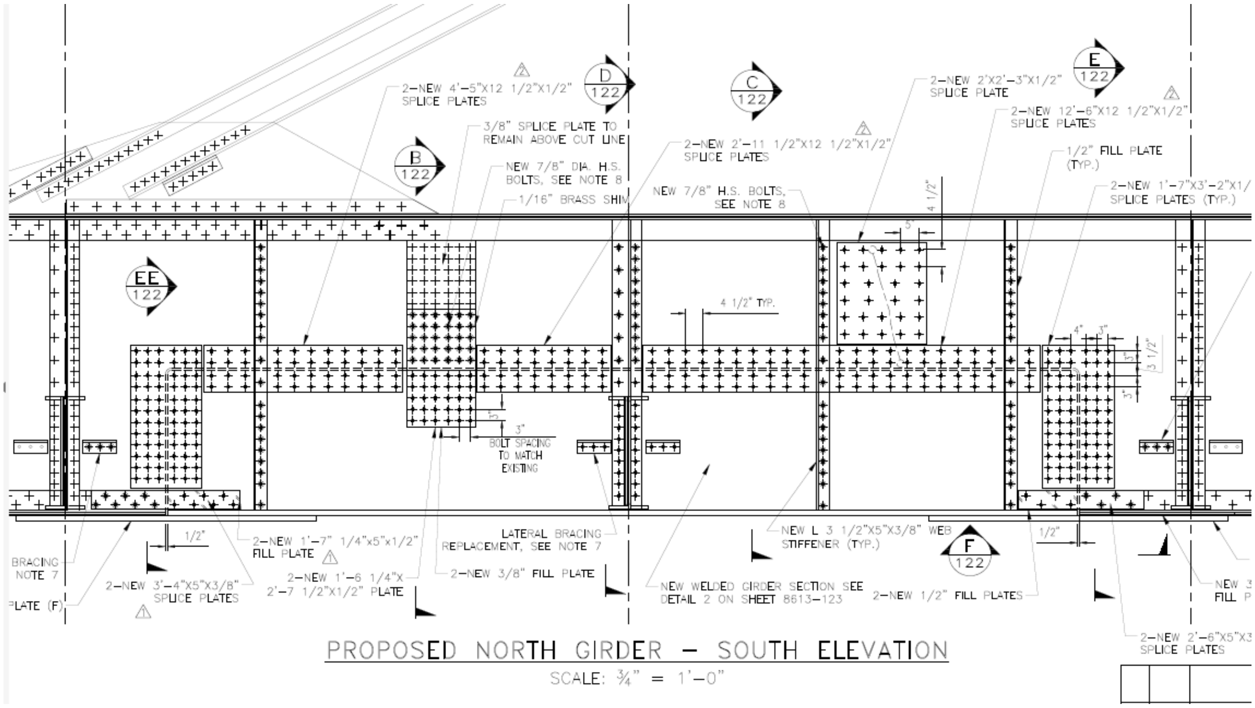
Threaded DSI rods used on either side of the counterweight stay arm along the North girder. A total of 50 kips of pressure was applied.

Square tubing with a hydraulic jack applying 50 kips of tension force on the bottom of the girder.

The proposed methodology was to remove approximately a 20 foot section of the North girder approximately 3 feet high, and replace with a new weldment and bolt in place with splice plates on either side of the new weldment.



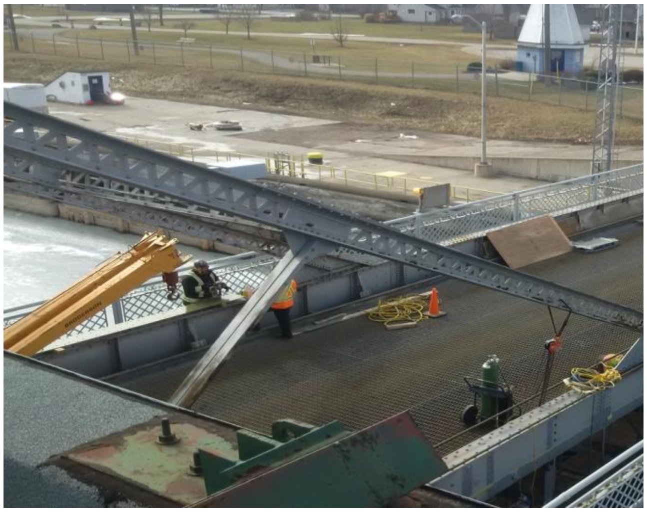
EXISTING NORTH GIRDER – SOUTH ELEVATION



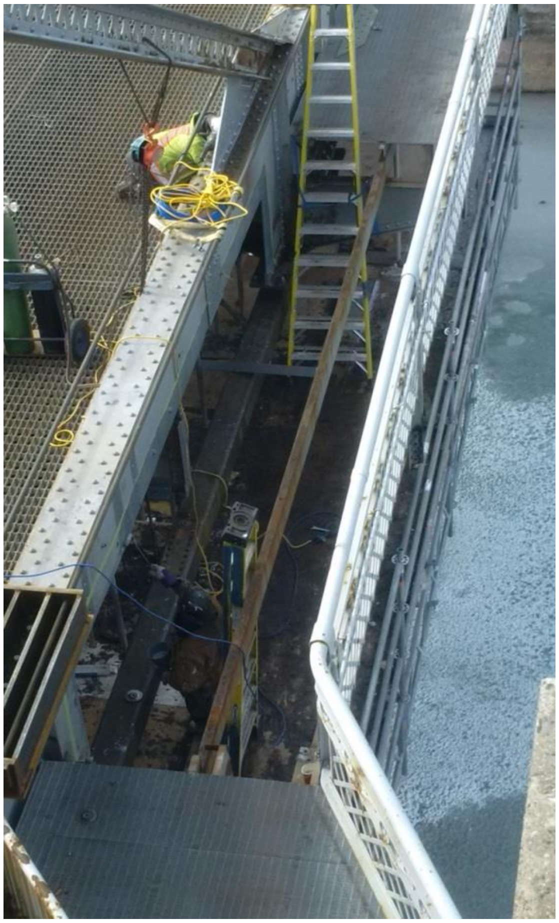
Reinforcing plates were added to the bottom flange to help strengthen and tie into the existing girder.

Section of North girder showing impact location and deformation.

Two 4-inch diameter holes were cut at each corner and the girder section was cut and removed in two pieces.



Top view of bridge with section of North girder removed.



Up close view of girder section removed, showing the threaded rod and square tubing jacking arrangement still in place.

New North girder weldment being located into position.

North girder installed with splice plates. Green primer coat visible on splice plates prior to field painting.

Splice Plates on North Girder After Field Painting

Bottom Flange of North Girder Stiffening Plate

Cross Bracing Repairs Done in 3 Bay Locations

Stiffening `T` Added to South Girder in 6 Locations

Top Flange of South Girder Stiffening Plate

Counterweight Stay Arm Stiffening Plate

Rack Support Stiffening Plate

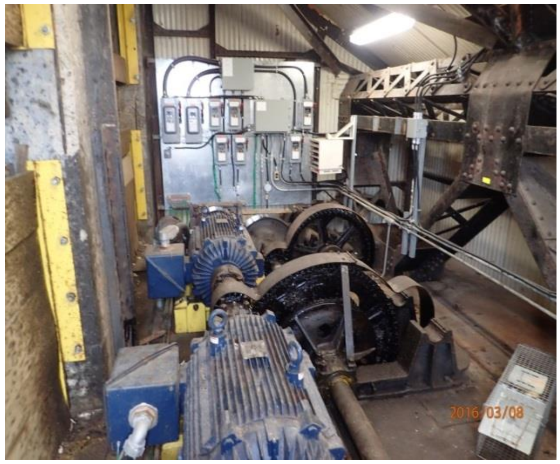
Bridge Lock Adapter Plate Welded on to Accommodate Latch Plate and Bridge Misalignment

Centering Device Relocated

Road Curb Re-Poured to Accommodate Bridge Misalignment

Weight Removed from the Lower Counterweight Pockets

Strain Gauges Installed for Bridge Balancing



Bridge 19 Machinery Room

Road Line Repainted

First Vehicle to Cross the Bridge After Repairs

Testing and Balancing

Steel plates were added to the counterweight pockets to compensate for the approximately 10,000 lbs. of structural steel added to the span during the repairs. This was the initial starting point of the balancing.

The bridge was operated in slow speed for the initial operation with people stationed at each corner to observe any rubbing or unusual noises coming from the bridge operation. The bridge operated multiple times without any issues.

The next step was the balancing which was accomplished by Hardesty & Hanover with strain gauge testing. Strain gauges were placed on the outboard tertiary pinion shaft on the North and South side of the machinery room. Data was recorded for three complete cycles of the bridge and then analyzed afterwards. The analysis showed a requirement to remove weight from the lower counterweight pockets to keep the span toe heavy and still achieve the desired alpha angle.

The bridge was placed back in operation as per the original schedule of March 18, 2016 at 5 pm. The community was very happy to have the roadway back in service.

Challenges

All projects at the St. Lawrence Seaway have time constraint challenges because of the short construction window without shipping traffic during the non-navigation season, between January and mid-March. This particular project schedule was even more constrained as it was tendered and awarded during the non-navigation season. When an issue arises with construction drawings or material availability, being able to communicate with the Consultant, Contractor and Owner becomes an issue with stringent timelines.

Winter conditions and working over water on a scaffold are always a challenge with limited space access to all the areas of the bridge requiring repair. Scheduling resources so they do not interfere with each other is very essential. The Contractor did a very good job of this.

Project Facts

- Professional Services awarded to Hardesty & Hanover, LLP ($240,000 CAD).
- Construction Contract awarded to Roberts On Site Group, Kitchener, Ontario, Canada ($540,000 CAD).
- Field Work commenced February 8th, 2016, completion date March 18th, 2016.